Smith Avenue High Bridge (High Bridge)
Spanning the Mississippi River at Smith Avenue
between Cherokee Avenue and Cliff Street
St. Paul
Ramsey County
Minnesota

HAER No. MN-5

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12-

PHOTOGRAPHS

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HAER
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62-SAIPA,
12-

HISTORIC AMERICAN ENGINEERING RECORD

Smith Avenue High Bridge (High Bridge)

HAER No. MN-5

Location:	Spanning the Mississippi River at Smith Avenue between Cherokee Avenue and Cliff Street St. Paul, Ramsey County, Minnesota UTM: A 15.491380.4975700 B 15.491960.4975060 Quad: St. Paul East
Date of Construction:	1887-1889 5 southern spans replaced 1904-1905 1 northern span reconstructed 1933-1934
Present Owner:	Minnesota Department of Transportation St. Paul, Minnesota 55155
Present Use:	None. Closed to all traffic on July 25, 1984
Significance:	The Smith Avenue High Bridge, a nineteenth century wrought iron Warren deck truss, is the longest and highest roadway truss bridge in Minnesota. It was designed by Keystone Bridge Co. of Pittsburgh, Pennsylania, the leading bridge building firm of the era. It provided an important link in the development of the heights area of St. Paul's west side.
Historian:	Susan Hodapp, November 1984
Transmitted by:	Jean P. Yearby, HAER, 1985

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SMITH AVENUE HIGH BRIDGE - 1889

ST. PAUL, MINNESOTA

I. INTRODUCTION

A. Location

Minnesota Trunk Highway 149 spanning the Mississippi River at Smith Avenue in the City of St. Paul, Ramsey County, Minnesota.

Latitude: A 44° 56' 13" B 44° 55' 51"

Longitude: A 93° 06' 34" B 93° 06' 07"

UTM: A 15/491380/4975700 B 15/491960/4975060

Quad: St. Paul East, MN

(See Field Record, MINN-5-83: Exhibit 4.)

B. Construction Date

July 1887 to May 1889.

C. Designer and Builder

General plans and specifications by A. W. Munster, City of St. Paul Bridge Engineer. Detailed designs and fabrication provided by Keystone Bridge Company of Pittsburgh, Pennsylvania. Assembled by the Horace E. Horton Company of Rochester, Minnesota.

D. Original and Present Owners

City of St. Paul 1889-1933.

Minnesota Highway Department 1933-present. (Now the Minnesota Department of Transportation.)

E. Present Use

None. Closed to all traffic on July 25, 1984. Projected demolition date: February 28, 1985.

F. *Significance*

The Smith Avenue High Bridge (known commonly as the "High Bridge" since its construction) is significant in its example of nineteenth century bridge engineering technology, and also in the transportation history of the area. Completed in 1889, it is one of the four extant major river crossings in the Twin Cities metropolitan area from the nineteenth century. The bridge's wrought iron Warren deck truss was designed and fabricated by Keystone Bridge Company, the leading American bridge building firm of the mid to late nineteenth century. It is a prime example of the lower chord pin and eyebar-connected type of bridge construction popular during this era. The structure also represents an intricate and graceful engineering solution to the problem of connecting two communities situated on high bluffs which are separated by a wide expanse of the Mississippi River flood plain. The bridge is 2,770 feet in length and, with the exception of the northernmost span, maintains a four-percent grade, rising from 80 feet above the river at the north end to 191 feet at the south. At the time of its construction, only the Poughkeepsie Bridge over the Hudson River had a greater combination of length and height.

The High Bridge was built to connect St. Paul's oldest residential neighborhood, West Seventh Street, with the last undeveloped first-ring neighborhood of Cherokee Heights in West St. Paul. It also served as a significant and vitally direct link to the southern Ramsey and Dakota county farming areas that sought St. Paul as a marketplace. The High Bridge was at once and continued to be an important and visually prominent landmark for the City of St. Paul as well as for the two interdependent communities it served. Until its closing, the bridge *continued to play an integral role in the economic and social life of St. Paul and its local neighborhoods.*

The High Bridge was placed on the National Register of Historic Places on August 6, 1981.

II. HISTORY OF THE BRIDGE

A. Local Neighborhood History

St. Paul was settled in the late 1830's when a number of fur traders, pioneers, and discharged soldiers from Fort Snelling established two separate neighborhoods along the banks of the Mississippi River, a few miles downstream from the fort.[1] One neighborhood was located around the Upper Levee or Landing (at the foot of what was later named Chestnut Street), where Edward Phelan, the city's first white settler, had built his cabin. The other neighborhood was located at the Lower Levee (at Jackson Street), and called itself "Pigs Eye" after the colorful bootlegging ex-soldier Pierre "Pig's Eye" Parrant. This neighborhood developed into the commercial area of downtown St. Paul, known then and now as Lowertown. The Upper Levee, or Uppertown, was maintained primarily as a residential neighborhood which grew alongside Fort Road (West Seventh Street). This road had been an oxcart trail connecting the neighborhood with Fort Snelling. Eventually linked together, the neighborhoods were named St. Paul after the Chapel of St. Paul was built in 1842.[2] (See Field Record, MINN-5-80: Exhibit 1.)

St. Paul was designated the territorial capitol in 1848. Immediately following designation, rapid land speculation and building construction spurred the development of the entire city, commercially and residentially.

Unlike Minneapolis, which had abundant waterpower provided by St. Anthony Falls to promote the milling and other industries, St. Paul's position at the head of practical navigation allowed it to develop into an important commercial center for the territory.[3] Thousands of immigrants, many of whom stayed to settle in the West Seventh Street area, disembarked from steamboats at the levees by the 1890's.[4] These immigrants came from Czechoslovakia, Germany, Scandinavia, Ireland, and Italy. Each ethnic group developed their own neighborhood within the community.[5] It is possible that these people were attracted to the area by the core of large industries within walking distance that included breweries, foundries, factories and the Chicago, St. Paul, Minneapolis and Omaha Railroad shops.[6]

Downstream from the High Bridge and three blocks north of the upper levee landing was the residential focus of the West Seventh Street neighborhood, Irvine Park. John Irvine cleared the area of trees between the park, which he had donated to the City, and the steamboat landing at the levee to encourage the development of a residential neighborhood around the park. The park and its surrounding homes were designated as Irvine Park Historic District in 1973, recognizing the historic significance of the area as the first residential neighborhood in St. Paul. It was around Irvine Park that many of the State's most prominent early citizens made their homes. Several of the mansions, including the city's largest concentration of pre-Civil War houses, still remain in this rehabilitated historic district.[7] (See Photos MINN-5-75 to MINN-5-79.)

The land directly across the Mississippi River from downtown St. Paul, along with most of southern Minnesota was opened to settlement in 1851 by the

Traverse des Sioux Treaty. This area has been known locally as the West Side since that time and is now a part of St. Paul.[8] *Historically and geographically, the area was divided by steep river bluffs into two neighborhoods - the Upper West Side, or Cherokee Heights, on top of the bluffs, and the Lower West Side, or Flats, northeast of Cherokee Heights between the river and the bluffs.*[9]

When the City of West St. Paul was incorporated in 1858, its charter boundaries included the Lower West Side and a large part of Cherokee Heights. Its citizens elected as its first mayor, George W.H. Bell, the West Side's first white settler. Unfortunately, mismanagement of funds plunged the City deeply into debt, and the City's charter was revoked in 1862. From 1862 to 1874, the City was under the jurisdiction of Dakota County. In 1874, by citizen vote, St. Paul annexed the area north of Annapolis Street, which became St. Paul's Sixth Ward. The southern area remained in Dakota County as the City of West St. Paul.[10]

After its initial incorporation as West St. Paul in 1858, concerted attempts were made to attract people to live in the West Side, but growth was hindered by lack of access across the river. There were ferries operated by John Irvine to the lower West Side before the St. Paul Bridge was built in 1859, and development of the Flats had prospered. French-Canadians, Germans and Irish were the first predominant ethnic groups to settle there. Unfortunately, the Flats were subject to frequent flooding. The opening of the High Bridge in 1889 finally allowed and encouraged development to continue atop the bluffs, which had previously been the only undeveloped area within walking distance of downtown St. Paul. The bridge provided direct access to the upper West Side as opposed to the steep, sharply curved roads winding up the bluff from the Flats, which were poorly made and difficult to navigate with a loaded wagon. The West Side's bluffs were so steep that streets often simply ended in stairways to reach lower levels.[11]

The West Side attracted the beer industry to its locale because of the system of natural caves in the sandstone bluffs. Many breweries used the caves for cooling and storing beer. Other early industries that were established on the Flats included foundries, quarries and manufacturing. 1950's urban renewal cleared many of the earlier industrial buildings for construction of the Riverview Industrial Park and the St. Paul downtown airport.[12]

B. Earlier St. Paul River Crossings

On March 4, 1854, the St. Paul Bridge Company was formed by an act of Minnesota's territorial legislature. The same day, Territorial Governor Willis Gorman approved the incorporation of the City of St. Paul. Together, these two acts encouraged the growth and development of the City across the Mississippi River, which eventually led to the annexation of the West Side to St. Paul.[13]

The St. Paul Bridge Company was formed to choose a location for a river crossing and to build a bridge at that site. Plans were drawn for the bridge by engineer J. S. Sewall, who was also superintendent of construction. The bridge, a wood and iron trestle structure 1,311 feet in length, was built where ferries had been operating to connect the community of 500 on the lower West Side to downtown St. Paul. The bridge company was to collect tolls from bridge users in order to pay for construction, which was *completed in June of 1859. Pedestrians were charged five cents, and two-horse teams 25 cents. Because of several financial problems which plagued the bridge from the start of its construction in 1856, the company was ordered by the State Legislature to sell the bridge to the City for $11,382 in 1867. The total construction cost was $161,855. The St. Paul Bridge was reconstructed in 1874, the same year the West Side was annexed to St. Paul and was renamed as the Wabasha Street Bridge at that time. The bridge was reconstructed again in 1900.*[14]

In 1886, the Robert Street Bridge was built by the Morse Bridge Company of Youngstown, Ohio.[15] *This bridge was located one quarter mile downstream from the Wabasha Street Bridge. The mid to late 1880's were years of prosperity for St. Paul, and a period of substantial financial and geographic growth. These two bridges spurred development on the West Side's river flats and soon the area was completely developed with breweries, quarries and manufacturing alongside the ethnic residential neighborhoods. The only remaining undeveloped area within walking distance of downtown was high on the steep bluffs of the West Side.*[16] *(See Photos MINN-5-73 to MINN-5-74.)*

C. Selection Of The Contractors

After four years of discussion and controversy, St. Paul Mayor Robert Smith was given legislative authorization for the City to issue $500,000 in bonds for a new bridge on January 18, 1887.[17] *That day the City Council also voted to request the City Engineer to "prepare plans and specifications for the construction of a new wagon bridge over the Mississippi in the upper part of the City". A special "Upper Town" Bridge commission from the Common*

Council selected the site to be between Forbes Street on the West Seventh side and Mohawk Avenue on the West Side bluffs. The corridor is now called Smith Avenue, named in honor of Mayor Smith.[18] *(See Photo MINN-5-23.)*

The contract for the substructure of the new bridge was awarded to Authur McMullen of the McMullen and Morris Company from Minneapolis on May 17, 1887 for $136,119. The council voted unanimously on McMullen's bid, the lowest received.[19] *Work on the substructure began in July of 1887.*

The contract for the superstructure, however, was met with considerable discussion. Although City Engineer L. W. Rundlett had recommended the contract be let to the lowest bidder, the Morse Bridge Company, it was awarded by a narrow margin to Charles L. Strobel on July 5, 1887. Strobel was a consultant engineer who represented the Keystone Bridge Company of Pittsburgh, Pennsylvania.[20] *(Appendix B.) Reconsideration of the contract was called for a month after the letting by some council members because of the suggestion that fraud had been involved in the awarding of the contract to Strobel. Strobel's bid of $340,324 was $29,324 higher than the Morse Company's bid of $311,000. Upon council request, Section 19 of the Municipal Code concerning contracts was read by the council clerk. The section read: "The Council shall award the contract to the lowest responsible bidder". City Engineer Rundlatt admitted he recommended Morse Bridge Company primarily because they offered the lowest bid, he not being especially versed in bridge building. A civil engineer was therefore consulted by the Committee on Streets and Bridges to consider the plans again.*[21]

Committee discussion of the awarded contract's adherence with the Municipal Code seemed to shift from the word "shall" to that of "responsible" in light of the consultant civil engineer's comments on the individual proposals. As discovered by the consultant, the Morse Bridge Company's plans were not as structurally qualified as those the Keystone Bridge Company, through Charles Strobel, had submitted. In addition, in several other bridge contracts around the Twin Cities, the Morse Company was consistently the lowest bidder, but the contracts were all awarded to higher bidders with superior designs. In fact, the Minneapolis City Engineer advised the St. Paul City Council that, "the Morse Bridge Company, notwithstanding their lower price, did not offer the best bridges in proportion to the prices". This issue was precisely the concern of the St. Paul City Council.[22] (Incidentally, in the case of the Robert Street Bridge, constructed in 1888, the contract awarded to the Morse Bridge Company was $39,000 above that of the lowest bidder.[23])

In a St. Paul Daily Globe newspaper article, William Hamm, Chairman of the Committee on Streets and Bridges, explained the Committee's decision to award the contract to Strobel: "A majority of the Committee came to the conclusion that the City would get more worth for its money under the bid of Mr. Strobel than under any other bid received". Mr. Hamm continued on to say that the Strobel proposal would build "a more permanent, better designed and more serviceable bridge in every way". The suggestion that the Council had unlawfully awarded the superstructure contract to Keystone Bridge Company was thus disproved and the Council judged itself responsible in its action.[24]

The superstructure's general plans and specifications were provided by City of St. Paul Bridge Engineer Andreas W. Munster. Detailed designs were provided by Charles Strobel. Keystone Bridge Company fabricated over one million wrought iron bridge components in Pittsburgh and shipped the complex truss structure to St. Paul by rail and steamboat. Keystone subcontracted the Horace E. Horton Company of Rochester, Minnesota to assemble the bridge across the Mississippi. Total cost of the bridge came to $476,443.[25] The High Bridge opened on Saturday or Sunday, May 25 or 26, 1889.[26]

III. DESIGN AND DESCRIPTION

The superstructure's design is a subdivided Warren deck truss (Appendix C.), using the pin and eyebar connected type of construction method. This method preceded the general use of rivets as connectors, and was the more popular of the two in the 1880's. The pin and eyebar method was recognized world-wide as the standard American practice in bridge building by the 1880's.[27]

Wide, forged eyebars made of wrought iron were introduced by Jacob H. Linville in 1861. (Linville later became President and Chief Engineer for the Keystone Bridge Company.) According to European and American bridge historian Llewellyn Edwards, there were several reasons for the favored use of pin and eyebar connections, the principle reason being economic. "When designed for a given loading it was lighter in weight; it could be fabricated in the shops and shipped to its destination without shop assembling its members; it required less time, less equipment, and less skilled labor to erect and, all in all, it cost less than fully riveted work". However, pins were inherently less rigid than rivets and required more supporting web members for stability in winds and increasing loadings. Pin and eyebar *construction diminished in popularity with the invention of the portable pneumatic riveter, which allowed rivets to be done faster in the field than before, and were stronger and more reliable.*[28] *(Photos MINN-5-11, MINN-5-14, and MINN-5-54.)*

Theoretically, according to Edwards, pin and eyebar connected construction was acceptable, but eventually major objections to its use arose from maintenance and service considerations. "In some cases the rupture of a single joint could result in the complete collapse of the structure, and joint movements induced wear and looseness". From 1890 to 1915, both pin and eyebar and rivet construction methods were used, with pin and eyebar connections primarily in longer spans where weight was a consideration. After 1915 and subsequent advances in bridge building technology, rivets were used almost exclusively.[29]

The High Bridge was originally assembled from nearly one million pieces of wrought iron weighing more than 3,000 tons.[30] *(See Photo MINN-5-5.) The bridge is 80 feet above the normal water elevation at the north abutment and 191 feet above at the south abutment. This creates a continuous four-percent grade, rising to the south, with the exception of the northernmost span of 90 feet which was reconstructed in 1933 and now has a three-percent grade. The bridge measures 2,770 feet in length.*[31] *(See Photo MINN-5-64.)*

Originally, the bridge's roadway was 24 feet wide, surfaced with four-inch cedar blocks laid over four-inch pine planks which were set in tar, and bordered with eight-inch pine curbs. The cedar blocks were considered a superior road surface because hard carriage wheels were quieter on the wooden surface than the more commonly used brick or cobblestone.[32] (See Photo MINN-5-45.) (However, in 1912, a petition was circulated, asking the City to resurface the bridge. On frosty mornings or after rain, horses would lose their footing on the slippery wood blocks. Groups of men with their teams would have to wait on one side of the bridge until the sun had sufficiently warmed and dried the bridge before attempting to cross. Apparently, there was no immediate action taken as requested by the petition, because no resurfacing of the bridge occurred until 1926.[33]) Sidewalks on either side of the roadway were eight feet one-inch wide, paved with three-inch thick pine planks, and were separated from the roadway by guard railings. The outside railings were made of ornamental wrought iron. (See Photos MINN-5-7 to MINN-5-9, MINN-5-22, and MINN-5-47.) The original design loading was for 100 pounds per square square foot, or 15 tons on four wheels, spaced six feet by ten feet, with an allowable 25% increase in stresses.[34]

The superstructure of the High Bridge consists of:

4 40-foot tower spans, riveted plate girder construction;

3 50-foot tower spans, lower chord pin-connected truss construction;

2 60-foot spans, riveted plate girder construction;

9 80-foot spans, riveted lattice girder construction;

5 90-foot spans, riveted lattice girder construction;

1 170-foot span, lower chord pin-connected truss construction; and

4 250-foot spans, lower chord pin-connected truss construction,

making a total of 28 spans. (See Photos MINN-5-13, MINN-5-27, MINN-5-29, MINN-5-32 to MINN-5-38, MINN-5-48 to MINN-5-50, MINN-5-56, and MINN-5-65 to MINN-5-66.)

The High Bridge is actually comprised of three different designs which had been modified to suit the span lengths required at this location. The most visually striking are the river spans which are of an inverted and subdivided Warren deck truss design. These spans extend from Pier and Bent 19 to Pier and Bent 27, a total of 1,320 feet. The other shorter spans are of either riveted lattice girder or riveted plate girder construction. The combination of these different design and construction methods illustrate Edward's claim that pin and eyebar connections were used in longer spans and riveted connections in shorter spans. The three 50-foot towers in the Warren deck truss design were originally specified and drawn to be riveted plate girder as shown in the Photos MINN-5-24 to MINN-5-25. Instead, it was decided at some point in the design and construction process to incorporate the towers into the Warren design, as seen in MINN-5-81.[35]

The substructure of the bridge consists of 25 dry land piers, which includes the north abutment, pier nos. 2-20, 25-28, and the south abutment; and four river piers, nos. 21-24, making a total of 29 piers. (See Photos MINN-5-3, MINN-5-16, and MINN-5-43 to MINN-5-44.) On these piers stand the supports for the superstructure, 27 wrought iron bents. (Appendix C.) Each dry land pier is actually a pair of masonry pedestals, one on each side of the line of the bridge. Lattice truss girders with cross-bracing rods are tied between the pedestal pair to form trestle bents. These bents utilize the concept of triangulation, apparent throughout the bridge's design, for rigidity. (See Photos MINN-5-51 to MINN-5-53, and MINN-5-57.) Fourteen of these bents (seven adjacent pairs) are tied together to form seven four-legged braced towers.[36] *(See Photos MINN-5-2, MINN-5-4, and MINN-5-15.)*

All dry land pier masonry is built with Mankato sandstone and is capped with loadbearing Mankato granite. All dry land foundation masonry is constructed on St. Paul limestone. The pilings are made of 9-inch (at the small end) Norway pine, spaced in a 3.5-foot grid, but the depth to which the pilings are driven is not indicated in the plans or specifications. Surrounding the pilings is three feet of concrete. The foundation masonry is constructed on two layers of timber, one eight-inch pine layer and one eight-inch oak layer.[37] (See Photo MINN-5-44.)

The river piers are solid pedestals (as opposed to the pedestal pairs in the dry land piers). These piers are of Mankato sandstone with two courses of Mankato granite comprising the integral icebreakers (Appendix C.) The foundation masonry is St. Paul limestone, which rests on four layers of timber: one six-inch and two eight-inch layers of pine, and one eight-inch layer of oak. The 150 pilings are positioned in a 3.2-foot grid, surrounded by 4.6 feet of broken stone.[38] (See Photo MINN-5-58.)

IV. REPAIR AND MAINTENANCE HISTORY

The High 8ridge has been repaired, altered and updated several times throughout the course of its history.* The first mention of repair to the bridge was made in the St. Paul Daily Globe in 1902. After lengthy praise of the bridge and its benefits, the newspaper states,

> "How a bridge of this character is subject to the treacherous bottom on which its massive piers rest, and the constant vigilance that must be maintained by those in charge of the City's bridges, was illustrated last year when an examination brought to light the startling fact that one of the 250 foot spans was gradually slipping from its foundation.

*For a complete account of all repairs made to the bridge, please see Appendix A.

> *That the public might not be startled, everyone connected to the Bridge Department was pledged to secrecy. Men were immediately put to work, the shoes were cleaned and the rollers which permit expansion and contraction brought back to a true bearing. This done, the span was brought to its proper position. The expense was small, possibly $200, but it saved thousands."[39]*

On August 20, 1904, a severe storm registering winds in excess of 180 mph (before the anemometer broke) hit St. Paul, and the High Bridge. The wind ripped the five southernmost spans (250', 170', 50', and two 60' spans) from the rest of the structure and dropped them 100 yards downstream. Contemporary accounts of the damage reported, "The wind cut out the span completely ... as it was, the wind in its work of destruction made useless the most expensive bridge in the City. Not a rod nor brace connecting the span with the piers was left hanging to the uninjured structure. Everything was carried out ..."[40] (See Photo MINN-5-69.)

There was no question that the High Bridge must be rebuilt. The link it provided the West Side residents and the southern farming areas to downtown St. Paul was too important to both sides of the river. The rebuilt portion of the bridge was constructed according to the plans of the original bridge with the exception of being built with mild steel rather than wrought iron. (Appendix C.) At first it was believed that part of the wreckage could be salvaged for reuse, but unfortunately, the damage was too great.[41] Today, those spans which were rebuilt with mild steel are the most severely deteriorated.

Any modifications in the reconstruction which would facilitate shopwork were permitted with the consent of the City Bridge Engineer. The steel members were fabricated by Carnegie Steel Company under contract with the St. Paul

Foundry Company. The Chicago Bridge and Iron Company (formerly the Horace E. Horton Company from Rochester, Minnesota) again assembled the components. The Kelly and Atkinson Company, another bridge building concern from Chicago, contracted to recover the wreckage from the river. Total reconstruction came to $61,000. The bridge was reopened in June of 1905.[42] (See Photos MINN-5-70 to MINN-5-71.)

In 1915, a request was made of the St. Paul City Bridge Engineer to determine if the High Bridge could withstand the extra loading of a street car line. Several reasons were given as to why this was not feasible. Exerpts from the Bridge Engineer's reply to the request illuminated the bridge's hitherto unrealized limitations:

> "This bridge was built in 1889, 26 years ago, practically all material is iron and the structure is designed according to specifications for loading and unit stresses considered sufficient at that time. The live load used consisted of 100 pounds per square foot for the floor and short girders, or trusses, for the longer spans this was reduced in proportion. The heaviest concentrated wheel load was 6000 pounds, which was allowed to be increased to 7500 pounds, with a corresponding increase in unit stress.
>
> The present 40-ton street cars with wheel loads of 10,000 pounds, will consequently greatly overstress the floor members.
>
> The main members in the longer spans will not be overstressed very much considering only the increase in loads, but the spans are pin-connected and the bracing consists only of light rods which means that the effect from fast moving cars will be greater than the figures indicate. The vibration will be excessive and probably dangerous. It may also be noted that the vibrations of the bridge will have some effect on the foundation for the piers.
>
> The bridge is now in good condition and will serve its purpose for light traffic for a long time to come, but I consider the structure insufficient for street cars and believe the reinforcement necessary to be too expensive in proportion to the result accomplished."[43]

In other correspondence concerning this issue, City engineers stated that reinforcing the bridge for a single street car line would cost $34,000. For a double line, the cost would be $41,000, plus the fact the bridge would impair normal buggy and vehicle traffic because of its narrow width. The same correspondence also states, "This bridge was built [26] years ago and was designed for a loading considerably lighter than would be the case if the bridge were built today".[44] It is interesting to note that in 1915 - nearly 70 years ago - it was realized that the bridge was underdesigned for the modern vehicle speeds of the era.

When the river flats on the north side of the river would flood, access to the flats was blocked; consequently, Northern States Power (NSP) employees needed a stairway down the side of the bridge in order to provide access to the NSP plant on the flats immediately west of the High Bridge. A steel stairway financed by NSP was built by the City of St. Paul alongside Piers 19 and 20 on the west side of the bridge in 1924.[45] (See Photo MINN-5-6.)

In 1933, the bridge, including the stairway, was passed from the jurisdiction of the City of St. Paul to that of the Minnesota Highway Department (MHD), now the Minnesota Department of Transportation (Mn/DOT). In that same year, MHD began work to reconstruct the northernmost span, Span 1, of the bridge where smoke from coal-burning Chicago, Milwaukee and St. Paul Railroad trains passing beneath the spans was surmised to be causing the accelerated deterioration of the bridge's wrought iron. In addition, because of the sharp turn in Smith Avenue at the north end, northbound vehicles had difficulty negotiating the turn while descending the rather *steep four-percent grade. The reconstructed span would also provide a west turn onto Cliff Street where no access had previously existed. The reconstruction of Span 1 entailed:*

1. *The removal of Span 1 in its entirety, plus partial removal of the north abutment (Pier 1).*

2. *Bent 2 was left in place to support Span 2.*

3. *The encasement of existing Bent 2 legs and horizontal struts in concrete. Protruding portions were burned off with a torch.*

4. *The north abutment was reconstructed to accommodate the widening of Span 1. The span was reconstructed at a higher elevation to provide a three-percent grade between the north abutment and Bent 2. (See Field Record, MINN-5-81: Exhibit 2.)*

5. *Construction of an additional reinforced concrete five-legged bent, No. 1A, which is located approximately 15 feet south of the north abutment. (See Photos MINN-5-1 and MINN-5-12.)*

6. *Construction of an additional reinforced concrete three-legged bent, No. 2A, which is located approximately 12 feet north of the concrete-encased Bent 2. The outermost legs were tied to the legs of Bent 2 with concrete beams, forming a five-legged tower.*

7. *The north end of Span 1 was widened and flared to eliminate the sharp turn to the east and to provide a west turn to Cliff Street. (See Photo MINN-5-10.)*

8. *Structural steel I-beams were used to replace the original superstructure trusses. The original 10-foot deep trusses were eliminated together with a lesser grade from the north abutment to Bent 2 to provide a more vertical clearance for the railroad tracks.*

9. *The placement of a new deck structure on Span 1, and the span was paved with brick. The original wrought iron bridge railings were salvaged and reused.*

At that time, a load limit on the bridge was imposed at 10 tons. The bridge reopened on May 24, 1934.[46]

Periodic maintenance of scraping, then sandblasting and repainting the bridge was discontinued in the 1950's when it was determined that the rate of section loss was being accelerated by the sandblasting process. It was also determined that because of the inherent design of the structure, it was not possible any longer to inspect, clean, or repaint many structural members. Furthermore, it became more important to be able to regularly observe the effects of corrosion and pack rust expansion between the hidden structural member surfaces and the bare outside surfaces.[47]

The High Bridge was again closed from May 20 to September 22 in 1958 for inspection and extensive repairs. Repairs completed at this time by the Whiting-Turner Company of Baltimore, Maryland included:

1. *The replacement of the wooden roadway surface with a concrete-filled steel grid which was covered with a bituminous overlay.*

2. *The placement of new steel guardrails to protect pedestrians on the sidewalks from vehicles. The sidewalks were reduced to seven feet in width.*

3. *The replacement of the original wood plank sidewalks, again with wood plank.*

4. *Street lighting on the bridge was replaced for the first time. The work was done by the Commonwealth Electric Company of St. Paul.*

Total cost of these repairs came to $552,149.[48] (See Photos MINN-5-26 and MINN-5-72.)

Mn/DOT closed the bridge in March of 1977, again for an in-depth inspection of the superstructure and the substructure. This inspection revealed severe and irreversible deterioration in many structural members. Some primary structural members were replaced and others were reinforced with steel totalling nearly $200,000 in repairs. The bridge was reopened on April 28, 1977. Another reduction in the load limit was imposed, this time to 3 tons gross vehicle weight.[49]

In-depth inspections were again conducted in 1980 and 1983-84. Extensive maintenance and repair was required in 1980, at the cost of $100,000.[50] The structural evaluation completed in July of 1984 revealed severe deterioration in the major members of the truss in the form of section loss (wearing away of the structural materials of wrought iron and steel) and stress fatigue (wearing out of the structural members resulting in fracture and eventual failure). The average section loss of primary truss members recorded in the 1980 inspection ranged from 28% to 38%. In 1984, the section loss ranged from an average of 37% to 48%. This increase indicated section loss was advancing at an alarming rate.

In addition, it was found that the sixteen roller and sliding bearing assemblies which take up the expansion and contraction movement within the truss system had, in effect, frozen in place and no longer worked. This was due, in part, to 95 years of Minnesota weather and temperature extremes. Frozen bearing assemblies were also caused by the effects of corrosion and the forces of gravity on the truss associated with the 4% grade. As a result, the additional stresses created by the lack of properly working bearing assemblies were absorbed by the structural members and ultimately forced tension members into compression and vice-versa. (See Photo MINN-5-14.) The stresses of daily modern traffic and probable unanticipated stressing presented considerable doubt as to whether or not the bridge could withstand these stresses in its already weakened condition, adding to the likelihood of sudden failure of major spans. The inherent weakness of the long since outdated pin and eyebar method of construction presented the added concern that the failure of one single pin would mean the collapse of an entire 250 foot span.[51]

In July of 1984, MN/DOT officials were faced with concluding that the bridge could no longer safely serve the motoring public. Even with substantial repair, eventual collapse of the bridge in the near future was inevitable. The projected date for the completion of the replacement bridge was 1987 or 1988. The High Bridge was closed permanently to all traffic, vehicular and pedestrian, on Wednesday, July 25, 1984.

Closing of the High Bridge marked the end of its 95 years of service as a river crossing. However, parts of the bridge, including pier masonry and the ornamental sidewalk railing, will be incorporated into scenic overlooks on both ends of the new bridge to commemorate the High Bridge and its chapter within the history of the City of St. Paul.

V. ENDNOTES

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5. Kunz, p.23.

6. Murphy, p.88.

7. Kunz, pp.22-24.

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16. Kunz, p.28.

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18. Proceedings, p.195.

19. Proceedings, p.261.

20. Proceedings, p.375.

21. St. Paul Daily Globe. "The Bridge Contract". Sunday, August 7, 1887. p.7.

22. St. Paul Daily Globe, p.7.

23. St. Paul Daily Globe, p.7.

24. St. Paul Daily Globe, p.7.

25. City of St. Paul: Department of Public Works, Bridge Department. 1887.

26. *There has been some difficulty in determining the exact opening date of the High Bridge. The St. Paul Daily Globe reported this on Thursday, May 23, 1889: "Large numbers of West Side visitors are now to be seen daily at the now almost complete uptown bridge... It is expected that the finishing touches will have been put on by next Saturday, after which the bridge will be open to traffic". The Globe then reported on Monday, May 27, "The new High Bridge across the Mississippi River, which was very recently opened to foot passengers, was thronged with curious sightseers throughout the day yesterday...". These articles indicate the bridge was opened either Saturday or Sunday, May 25 or 26, 1889. No mention of an exact opening could be found in any other local newpapers.*

27. *Edwards, Llewellyn Nathaniel. A Record of History and Evolution of Early American Bridges. Orono, Maine: University Press, 1959. p.104.*

28. *Weitzman, David. Traces of the Past: A Field Guide to Industrial Archeology. New York: Charles Scribners Sons, 1980. pp.79-81.*

29. *Weitzman, p.80.*

30. *St. Paul Weekly Pioneer Press. "How the High Bridge Was Built". Sunday, November 11, 1888. p.19.*

31. *Minnesota Department of Transportation (Mn/DOT). "Request for Determination of Historical Eligibility". State of Minnesota: June, 1980. p.4.*

32. *Mn/DOT, p.7.*

33. City of St. Paul: Department of Public Works, Bridge Department. 1912.

34. Mn/DOT, pp.4,7.

35. City of St. Paul: Department of Public Works, Bridge Department. "Specifications for the Superstructure of the High Bridge", 1887.

36. City of St. Paul, Bridge Department. "Specifications for the Superstructure", and original plans for the High Bridge, 1887.

37. "Specifications for the Superstructure".

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40. St. Paul Pioneer Press. "High Bridge is Wrecked". Sunday, August 21, 1904. p.2.

41. City of St. Paul, Bridge Department. "Specifications for Rebuilding a Portion of the High Bridge". 1904.

42. Mn/DOT, p.8.

43. Grytbak, Martin, St. Paul Bridge Engineer. Memorandum to Oscar Claussen, St. Paul City Engineer. June 4, 1915.

44. Claussen, Oscar, St. Paul City Engineer. Memorandum to N. M. Goss, Commissioner of Public Works. July 12, 1915.

45. Mn/DOT, p.8.

46. Mn/DOT, pp.10-12.

47. Differt, Douglas, Mn/DOT District 9 Engineer. Memorandum to William Lake, FHWA Division Administrator. February 12, 1982.

48. Mn/DOT, p.13.

49. Mn/DOT, p.13.

50. Mn/DOT, p.13.

51. Mn/DOT. "Structural Evaluation Summary". State of Minnesota: June, 1980. pp.1-4.

VI. PROJECT INFORMATION

This document was prepared pursuant to the regulations of the Advisory Council on Historic Preservation, "Protection of Historic and Cultural Properties" (36 CFR Part 800), and Section 106 of the National Historic Preservation Act of 1966, as amended (16 U.S.C. Sec. 470). The documentation will fulfill the requirements of the Memorandum of Agreement to mitigate the adverse effect of the replacement of the Smith Avenue High Bridge. This Agreement was signed in June, 1982 by the Advisory Council on Historic Preservation, the Minnesota State Historic Preservation Officer, and the Federal Highway Administration.

Funding for the Smith Avenue High Bridge Replacement Project was provided by the Federal Highway Bridge Replacement Program, Discretionary Fund (80%), and the Minnesota Department of Transportation Bridge Replacement Program of the Highway Improvement Program (20%). The agency enacting the Replacement Project is the Minnesota Oepartment of Transportation (Mn/DOT), Oistrict Nine.

Historical documentation was researched and written by Susan Hodapp, Research Historian for the Smith Avenue High Bridge Replacement Project, from June to December, 1984. Photographic documentation was prepared by Oavid R. Gonzalez, Mn/OOT photographer.

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APPENDIX A
Events Schedule

YEAR	DATE	EVENT
1887	July	Construction of substructure begun
1889	May 25	Construction completed, bridge opened
1901		River bent repairs made secretly
1904	August 20	Windstorm rips 500' from south end
1905	June	Bridge reopened
1911		North stairway to levee built
1912	October 26	Citizens' petition to resurface bridge
1915	June	Streetcar study concludes bridge inadequate for streetcars
1924		NSP stairway built between Piers 19 and 20
1926		Distance between Piers 2 - 16 refloored with wood plank
1928		Distance between Piers 16 - 24 refloored with wood plank
1933-34		Reconstruction of Span 1
1934	May 24	Bridge reopened; 10-ton weight limit imposed
1937		South 550' of asphalt planks replaced with creosote blocks
1948	Sept. 8 - Nov. 10	Piers 24 - 29 refloored
1957	May 23	Load limit increased to 15 tons
1958	May 20 - Sept. 22	Repairs; bridge redecked with steel grid in concrete; lighting replaced

YEAR	*DATE*	*EVENT*
1959	August	*North stairway removed*
1967		*South 600' wooden plank sidewalks and stringers replaced*
1974		*Load limit restricted to 9 tons*
1977	March	*5 week in-depth inspection reveals severe deterioration*
1977		*Load limit restricted to 3 tons*
1977		*Metro Council ranks High Bridge top bridge replacement priority in area*
1980		*Major reinforcing and repairs after in-depth inspection*
1983-84		*In-depth inspection*
1984	*July 25*	*Bridge closed to all traffic, vehicular and pedestrian*
1985	March	*Projected demolition*
1987	Fall	*Projected opening of new bridge*

APPENDIX B
Biographical Sketches

KEYSTONE BRIDGE COMPANY

Keystone Bridge Company was organized from the bridge building firm of Piper and Schiffler in 1865. Andrew Carnegie, Jacob H. Linville, John Piper, Aaron Schiffler and Tom Scott each invested $1,250 to found Piper and Schiffler in 1862. Carnegie, at that time, was the director of a section of the Pennsylvania Railroad, which he left in 1862 to organize Piper and Schiffler. He became vice president of Keystone in 1865. Jacob Linville became president of Keystone after serving as engineer of the Pennsylvania Railroad, where he had specialized in the construction of bridges and buildings for the railroad's trains and tracks. Aaron Schiffler was in charge of the bridges on the railroad's lines. Tom Scott was a good friend of Carnegie's from the Pennsylvania Railroad and often collaborated on investments with him.

Carnegie was impressed that "iron was the thing" when he realized traffic on one track had been held up for eight days because a wooden bridge had burned. Cast iron was at first used in Keystone's structures, but wrought iron soon took its place[1] and was initiated for use in all principle truss members by Linville and Piper.

Keystone quickly expanded to include the design and fabrication of highway bridges as well as railroad bridges. Keystone fabricated material for the famous Ead's Bridge in St. Louis, which was opened in 1874 and was the first cast steel arch bridge ever built.[2] Carnegie had a financial as well as technical interest in the bridge, being a principle stockholder and seller of bridge bonds for the structure. Carnegie made a substantial portion of his early fortune in connection with the Ead's Bridge.[3]

Carnegie considered Keystone his pet company because it was his first and it parented all other Carnegie works. "In the completeness, extent and adaption of all the tools and appointments required for heavy construction, these works are unrivaled in this country, while, at the same time, they possess every facility requisite to the construction of iron roofs, fireproof buildings, turntables, roadway bridges, wooden bridges, and general foundry and machine work."[4] The increasing demands of Keystone for structural beams and plates convinced Carnegie that he should control his own source of supply of iron. This was his first move toward the creation of a vertical organization of his business interests. It is interesting to note that at this point in time, the manufacture of iron was still secondary to Carnegie's interest in bridge building. The Union Iron Mills were established mainly as a subsidiary or as a source of supply for Keystone.[5] Keystone's standardized wrought iron and tubular structural columns, made up of riveted circular segments, identify clearly Keystone bridges throughout the country. Because of these innovative efforts, Keystone Bridge Company is considered a pioneer in bridge metal truss technology.[6] (See Field Record, MINN-5-82: Exhibit 3.)

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JACOB H. LINVILLE, President of Keystone Bridge Company

Linville kept breaking his own records for long-span railroad bridges throughout the 1860's and 1870's. His first was a 320 foot channel span for the Steubenville, Ohio bridge built over the Ohio River and is considered by historians to have inaugurated the era of long-span bridges. At 515 feet, Linville's Ohio River bridge at Cincinnati, completed in 1870, was the longest single span of the time. He modified the Whipple trapezoidal design to increase its strength and rigidity, retaining the double-intersection principle.

From: Weitzman, David. Traces of the Past. A Field Guide to Industrial Archeology. New York: Charles Scribners Sons, 1980. p.107.

CHARLES L. STROBEL, Superstructure contractor representing Keystone Bridge Company, detail design engineer

Charles L. Strobel was born in Cincinnati, Ohio in 1852. He received his education in civil engineering from the Royal Institute of Technology at Stuttgart, Germany. A year after graduating, he began work as a draftsman for the Cincinnati Southern Railway and later became assistant engineer there.

From 1878 to 1885, Mr. Strobel was Chief Engineer and assistant to the president at Keystone Bridge Company. He was also the consulting engineer for Carnegie, Phipps and Co., Ltd., where he designed standard sections for steel beams and introduced the Z-bar column. (See Photo MINN-5-59.)

From 1885 to 1893, Strobel relocated in Chicago as a representative of the two Carnegie companies mentioned above. In Chicago, he became a leading and prominent figure in the development of steel skeleton construction of skyscrapers. In 1893, he organized the Strobel Steel Construction Company for the purpose of consulting and contracting the construction of bridges, viaducts, turntables, buildings and other structures of iron, steel, wood and other materials. The construction company was incorporated in 1905 and dissolved in 1942. Strobel retired in 1926, and died on April 4, 1936 at the age of 83.

From: Chicago Tribune. "C. L. Strobel, Sr., Leader in Steel Building, is Dead", April 5, 1936.

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ARTHUR McMULLEN, Substructure contractor

McMullen and Morris of Minneapolis, according to an advertisement in the 1889-90 St. Paul City Directory, specialized in "All Kinds of Heavy Masonry and Foundation Work - Timber, Piling and Earth Work - Railroad Buildings - Highway and Railroad Bridges of Stone, Iron, Combination, or Wood Designed *and Built - Docks - Water Supply and Sewage Systems". The ad went on to say "Stone Quarries at Minneapolis, Mankato and Morton, Minnesota, Brickyards at Menomenie, Wisconsin".*

From: St. Paul City Directory, R.L. Polk and Co. 1889-90. p.35.

HORACE E. HORTON, Subcontractor

Horace Horton was born in New York in 1843. At age 15, his family moved to Rochester, Minnesota. He returned to New York to attend school at Fairfield Academy where he studied surveying and civil engineering. Upon his return to Rochester, Horton built many bridges in the vicinity of Olmsted County for his company, the Horace E. Horton Company. He served as both Rochester City Surveyor and Olmsted County Surveyor for several terms. The Horton Company grew, and built several large bridges around the country, including bridges at St. Paul, Fort Snelling, and St. Louis.[1]

On July 1, 1889, the Horton Company was merged with Kansas City Bridge and Iron Company and relocated in Chicago, becoming the Chicago Bridge and Iron Company. George and William Wheelock and Horace Horton were co-owners of the new company.[2]

1. *Leonard, Joseph A. History of Olmsted County, Minnesota. Chicago: Goodspeed Historical Association, 1910. p.207.*
2. *Imberman, Eli W. "The Formative Years of the Chicago Bridge and Iron Company". Ph.D. diss., University of Chicago: August, 1973. p.264.*

ANDREAS W. MUNSTER, City Bridge Engineer

Andreas Wendelbo Munster was born in 1853 and lived in St. Paul from 1884 to 1906. During these 22 years, he served the City of St. Paul as Chief Bridge Engineer. In this time, he had provided general designs for the Robert Street and Smith Avenue High Bridges. He also recommended the construction of the Third Street, Sixth Street, and Lafayette Avenue Bridges, and designed the rebuilt portion of the Wabasha Street Bridge. There were several other bridge projects in St. Paul as well during Munster's service.

In April of 1904, Munster was appointed Chief Engineer of the Great Western Railway after his position as Bridge Engineer for St. Paul.

In 1906, Munster opened an office in Seattle as consulting engineer and was consultant to the Chicago, Milwaukee and St. Paul Railway Company from 1908 to 1911. He died in 1929.

From: Norwegian American Technical Journal. July, 1929. p.5.

L. W. RUNDLETT, City Engineer

Rundlett was born in Maine in 1846. After completing his education, he immediately began work as a construction engineer. He came to work in St. Paul in 1871 as a surveyor for the St. Paul and Pacific Railway. In 1874, he became Assistant City Engineer, later becoming City Engineer until March of 1911 when he was succeeded by Oscar Claussen. Rundlett died in St. Paul on October 13, 1916.

From: St. Paul Pioneer Press. Saturday, October 14, 1916. p.1.

APPENDIX C
Glossary

Warren Truss - Truss bridges, consisting of members vertically arranged in a triangular pattern, can be used when the crossing is too long to be spanned economically by simple plate girders. Where there is sufficient clearance underneath the bridge, the deck bridge is more economical than the through bridge because the trusses can be placed close together, reducing the span of the floor beams. In the Warren truss design, the triangle is equilateral, which provides rigid construction inasmuch as there can be with no relative movement between the bars. This concept of triangulation is carried throughout the entire structure. The design is practical as well - considerably less metal was required in the Warren truss than in other truss designs.

The Warren truss, which was patented in 1848 by two British engineers, has, in common with other trusses, parallel, longitudinal, upper, and lower members. The uppermost member is called the top chord, the lowermost is the bottom chord. The diagonal members joining the top and bottom chords at each end of the truss are called end posts. All other members between the top and bottom chords, whether diagonal or vertical, are called web members. The Warren truss consists of a single triangulation of diagonals - the diagonals do not cross each other between their points of intersection on the top or bottom chords. The diagonal in every other panel of a Warren truss is in compression. Vertical web members are optional, they may or may not be used.

The High Bridge's four river spans are of an inverted subdivided Warren deck truss design. A deck truss has the deck structure on the top chord of the superstructure web. A through truss has the deck structure supported by the bottom chord of the web--passage is through the superstructure. The subdivided Warren was used in special cases where the floor was to be shallower and spans longer than normal. The additional vertical members in the subdivided Warren provide immediate support for the deck, which means the rods are heavier, making them more like posts than rods.

Icebreaker - Past practice, particularly in the case of older bridges over a river built upon stone piers, has included the provision of an "icebreaker". The icebreaker is a part of the pier structure, on the upstream side of the river. The leading edge of the river piers are battered (slanted) - typically thirty degrees from the vertical. In addition, the leading edge terminates in a sharp peak rather than a rounded or blunt configuration.

The icebreaker minimizes the transference of impact energy from ice floe, inasmuch as the direction of the impact would otherwise be primarily normal to the leading edge of the pier. When an ice floe strikes the icebreaker, it tends to be sheared in two by the sharp leading edge. The floe tends to ride up the battered leading edge of the pier and cracks transversely as well.

This mechanism of longitudinal shearing and transverse cracking of colliding ice floes minimizes impact energy transference to the pier. Thus the bridge structure is not nearly as subject to damaging vibrations caused by ice floe collision with the piers during cold winter months.

Bent - *A bent in the terminology of the original bridge construction plans, is a relatively tall metal supporting unit for the bridge superstructure. The bent, in the case of the High Bridge, has two legs; an east leg and a west leg. The two legs are tied together by horizontal struts and by diagonal cross-bracing rods called counters. The orientation of the bent is transverse to the length of the bridge. The bent is rigid in the transverse direction, but free to rock from the vertical in the longitudinal direction. A bent which stands alone is essentially a two-dimensional structure, and is termed a trestle bent. (A bent may have, as in the case of the reconstructed northernmost span, more than two legs in the same plane.)*

Wrought Iron - *Wrought iron is a low-carbon, high phosphorous form of iron, very high in intentional slag content (1.0 - 3.0%), which is mechanically mixed with the material. Slag is comprised of several non-ferrous inclusions in all iron ore or pig iron, and is undesirable in high-quality steels.*

In earlier times, wrought iron was produced by heating iron ore to a semi-molten state, which prevented slag separation from the iron. The material could not be cast, but had to be handworked, or wrought, to the desired shape. This handworking process became obsolete after the establishment of the Bessemer steel-making process around 1870. Bessemer steel has an inherently high slag content, and its engineering qualities vary from one heat to the next. This steel is used where high-quality steel in not required.

It is thought that the high slag content in wrought iron gives the material its unique engineering qualities of ductility, ease of working and welding, *superior resistance to service conditions involving corrosion, shock and fatigue. All low-carbon materials, steels or wrought iron, exhibit less strength than ordinary structural steels.*

Mild Steel - "Mild steel" is an imprecise term to denote a low-carbon unalloyed structural steel. Maximum carbon content of low-carbon steels is by definition set at 0.20 percent. Low-carbon steels are not amenable to hardening by heat treatment. Some degree of hardening is obtained in the cold-rolling process, by virtue of work-hardening in the direction of rolling. Low-carbon steels also exhibit relatively low yield strength. They are suitable for large beams for bridges since it is not feasible to heat-treat (quench and temper) pieces of this size. Yield strength may be increased by the addition of small amounts of alloying elements.

Structural Steel - Development of the open-hearth steel-making process made possible the precise control of engineering properties of steels. The open-hearth process was developed a few years after the Bessemer process was devised. Precise control of carbon content, critical to hardenability characteristics of steels, was provided. Also, the majority of slag is floated off, resulting in a steel relatively free of unwanted impurities.

Structural steels may be classified into two very broad categories: carbon steels and low alloy/high-strength steels.

Carbon Steels (carbon content greater than 0.20 percent) are amenable to hardening by heat treatment. These steels may be hardened by heating to the appropriate temperature, which changes the space-lattice structure of the crystals. Upon rapid cooling, accomplished by oil or water quenching, *retention of this high temperature space-lattice structure is effected, and carbon is prevented from precipitating out of the solution. This yields a hardened steel, the hardness depending on the specific carbon content and the temperature at which the piece is drawn from the quench. This process is followed by tempering at the appropriate temperature for the purpose of internal stress relief. The process is not feasible for large structural beams for bridges. However, when the steel is hot-rolled to shape in the mill, isotropic (directional) workhardening occurs, as well as isotropic increases in yield strength and impact strength. A finish cold-rolling will further increase these directional properties. The presence of carbon enhances development of desirable engineering properties when the steel is hot or cold-worked. Carbon steels rather than alloy steels are used for the majority of construction work, due to a considerable cost differential.*

Low alloy/high strength steels are essentially ordinary structural steels, or low-carbon steels, with one or two percent of alloying elements added. The yield strength of ordinary (carbon) structural steels as well as low-carbon steels is approximately doubled by addition of the appropriate alloying elements. Other alloying elements will increase resistance to atmospheric corrosion. For bridge construction, use of these alloy structural steels has generally been inhibited by their high cost.

Information for Appendix C compiled from:

Mn/DOT Request for Determination of Historical Eligibility. St. Paul, June, 1980. Appendix B.

McGraw-Hill Encyclopedia of Science and Technology. 5th Edition, Volumes 2 and 15. New York: McGraw-Hill, Inc., 1982.